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GROUND-TO-AIR COCHANNEL INTERFERENCE AT 2900 MC

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ABSTRACT

Estimates are given of average ground-to-air interference for a ground installation utilizing a Bendix ASR-1 vertically polarized antenna operating at 2900 Mc. Coverage is defined in terms of 0, 6, 12, and 18-db protection ratios with respect to a similar installation sending out an undesired signal, with station separations of 10, 50, 100 and 150 miles being considered. "Coverage" here is not synonymous with the usual concept of service, for no minimum signal is taken into account, but only the ratio between desired and undesired field strengths. Limitations of the estimates are discussed, and their derivation is explained in an appendix to the report.

1. INTRODUCTION

This report was prepared at the suggestion of the Air Navigation Development Board. Estimates are given of average interference-limited coverage to be expected from a ground installation utilizing a Bendix ASR-1 antenna in the presence of undesired signal from a similar installation. Provisional estimates of this coverage, defined in the great circle plane between the two ground stations, have been derived for station separations of 10, 50, 100 and 150 statute miles.

No attempt is made to define a minimum usable signal from the desired station; service is assumed to be limited only by cochannel interference. The volume of space within which the ratio of desired to undesired signal is equal to or greater than a given protection ratio is defined as completely free from interference. Once a protection ratio is assigned, "interference" becomes an either/or proposition and there is no room for degrees of interference. To present an adequate picture of varying degrees of interference, it is necessary to consider several different protection ratios. The ratios chosen here are 0, 6, 12 and 18 db.

Further conditions assumed in the coverage calculations are: 1) transmission through a standard atmosphere over a smooth spherical earth having the ground constants of good ground, 2) a frequency of 2900 Mc, 3) vertical polarization, and 4) ground installations of equal power radiated from ASR-1 antennas oriented towards each other. The effect of standard atmospheric refraction is included by using the customary four-thirds earth radius.

The ASR-1 was designed to fill in nulls in the service pattern by discriminating against ground-reflected rays, as is shown by the free-space vertical radiation pattern of the antenna in Fig. 14. This discrimination also reduces the interference from the nearby facility in the region of air space around the desired facility.

The frequency involved here is such that practical antennas are many wavelengths high, so that there are a great many lobes in the signal pattern. For instance, there are thirty-one lobes in the first ten degrees above the radio horizon in the case of 2900 Mc radiated from an antenna 30' high. The interference pattern resulting from the interaction of the lobe structures of the desired and interfering stations is very complicated for any usual combination of ground antenna heights. Also, the positions of the lobes from each station would change constantly with variable atmospheric conditions.

It was decided in attacking the problem of estimating interference-free coverage to make our computations independent of ground antenna heights. How this was done will be explained later in the report. Reference should be made to Fig. 15 to see what an interference pattern looks like for the particular case of two ground antennas, both 30' high and with a separation of 150 miles between them. The shaded area in this figure is the interference-limited coverage calculated for a 12 db protection ratio. A larger protection ratio would result mainly in less coverage above the radio horizon of the undesired station. The dashed lines in the figure are the radio horizons of the ground stations. The dotted lines are 12-db reference curves calculated independently of ground antenna heights by a method described below.

It may be seen from Fig. 15 that the service area of the desired station is limited essentially by a curve running along the radio horizon of the interfering station and that part of the inner dotted curve which lies above the radio horizon of the interfering station. Whether this general character will hold for other antenna heights and other separations between facilities has not been completely investigated as yet. However, it is felt that a satisfactory estimate of interference-free coverage may be obtained from such an approximation.

2. USE OF CURVES

Figs. 1 through 12 are grouped by station separation. Figs. 1 through 3 refer to the 10-mile separation of stations, 4 through 6 to the 50-mile separation, 7 through 9 to the 100-mile separation, and 10 through 13 to the 150-mile separation. The first figure for each separation has three graphs on it, corresponding to the three protection ratios of 6, 12 and 18 db. Each of the graphs shows 1) an area of solid inking where interference-free coverage is always expected, regardless of ground station antenna heights, 2) a shaded area where the inter-

ference pattern is a function of the combination of ground antenna heights, and 3) at the extreme right of the graph an area of no shading where interference always may be expected. The second figure for each separation shows the areas where interference-free coverage is expected for any combination of ground antenna heights, with 0, 6, 12 or 18-db protection ratios. This figure in each case shows coverage under "worst" conditions. The third figure for each separation shows where interference is always expected, regardless of the choice of ground antenna heights. This figure shows coverage under "best" conditions.

Fig. 13 groups all the curves derived for the 150-mile separation of stations.

To estimate the interference-free coverage for a given protection ratio and pair of ground antennas, we define as "free from interference" that area which is below the appropriate curve in the figures for coverage under "worst" conditions. There is an additional wedge of coverage below the horizon of the undesired station. This wedge continues to a distance just short of the intersection of the radio horizons of the desired and undesired stations. Referring again to Fig. 15, it will be seen that this simple method of estimating interference-free coverage gives very nearly the entire coverage to be expected.

With a higher antenna at the undesired station, the boundaries of coverage will approach the curves dotted in Fig. 15, but will never cross over them.

3. DERIVATION OF THE CURVES

Let M' and M" be defined as proportional to field strengths at lobe maxima of the desired and undesired stations, respectively; similarly, let m' and m" be proportional to field strengths at lobe minima. The curves of Figs. 2, 5, 8 and 11 correspond to points in space where the ratio m'/M" equals the indicated protection ratio. The curves of Figs. 3, 6, 9 and 12 correspond to points where the ratio M'/m" equals the indicated protection ratio. These same curves are the boundaries of the shaded areas of Figs. 1, 4, 7 and 10.

The curve separating the solid inking and shaded areas of the 6-db graph in Fig. 10 (which is the same as the 6-db curve of Fig. 11) corresponds to all points where the ratio m'/M" equals 6 db. This is called coverage under "worst" conditions because m'/M" is a ratio of a minimum desired to a maximum undesired signal. Such a curve indicates the points where the minimum of a desired signal lobe corresponding to a specified field strength F (in db) could be made to coincide with the maximum of an undesired signal lobe of (F - 6) db. Every point on such a curve corresponds to a different combination of ground antenna heights. Within the curve there will always be more than 6-db protection with any

combination of antenna heights. There is a similar interpretation for the other curves. The appendix to this report describes in more detail just how the curves were obtained.

The effect of antenna height on field-strength ratios below the horizon of either antenna is neglected in our treatment of this problem which makes use only of four-thirds earth interference theory to arrive at a solution. No computed point on any graph corresponds to regions beyond the radio horizon of either antenna, for it was felt that the information to be gained by evaluating the signal below the horizons did not warrant the rather cumbersome computations involved. Curves are extrapolated to zero altitude, where actually no service is expected, and the interference estimates are most reliable at the higher altitudes. At low altitudes, lobe patterns would exist only for very high antennas, except where the stations are very close together, and curves in this report are to be interpreted as indicating average limits of realizable coverage for all possible ground antenna heights.

APPENDIX

A brief explanation is given in this appendix of the methods used to derive the curves of Figs. 1 through 13. For a fuller understanding of these methods reference may be made to the paper, "Service Range for Air-to-Ground and Air-to-Air Communications at Frequencies Above 50 Mc", by R. S. Kirby, J. W. Herbstreit and K. A. Norton, pages 525-536 of the Proceedings of the IRE, May, 1952.

The last page of the above-mentioned paper gives a formula for the ratio of space-wave field strength to free-space field strength as a function of the grazing angle of a ground-reflected ray and the distance from the transmitter to receiver. This formula is stated in terms of the electrical path difference θ between direct and reflected rays, the reflection coefficient $|R'|$ and phase lag $(\pi - c)$ associated with ground reflection, and the divergence D of energy reflected from a convex spherical surface. This ratio is called "radio gain" in this report and is denoted by the symbol g:

$$g = \left[g_1^{\,2} + (g_2 D \ |R'|)^2 - 2 g_1 g_2 D \ |R'| \cos(\theta - c) \right]^{\frac{1}{2}} \qquad (1)$$

where g_1 and g_2 are the antenna directivity voltage gain factors for the direct and ground-reflected ray, respectively. This equation corresponds to a free-space transmitting antenna pattern which may show a varying discrimination against radiating voltage as a function of the angle of radiation; examples would be high-gain and tilted-array installations where the ground-reflected ray is discriminated against. Referring to Fig. 14 of this report, antenna directivity voltage gain factors can

differ markedly, depending upon the angle made with the horizontal by the direct and ground-reflected rays.

As may be seen from eq. (1) maxima in a lobe diagram showing the locus of all points in space where a given field strength exists must correspond to values of $(\theta - c)$ which are odd multiples of 180°, and, similarly, minima correspond to values of $(\theta - c)$ which are even multiples of 180°. The quantity θ is a function of antenna height, as is also the divergence D. Simplifying our problem by not specifying ground antenna heights, we consider only values of g corresponding to maxima or minima and assume D is unity at all points in space. (This is a fairly good approximation for the problem at hand.) The formula for g then becomes:

$$g = g_1 \pm g_2 \, |R'| \tag{2}$$

with the free-space field E_{fs} represented as:

$$E_{fs} = \frac{E_o}{d} \tag{3}$$

where E_o is the field strength due to the direct ray alone at unit distance from the antenna in the direction of maximum gain and d is the distance to the point in space in question.

Radio gain is a point function. With each point in space there is associated a value of g, and the field at this point will be proportional to $\frac{g}{d}$, or equal to $\frac{E_o g}{d}$ in our present notation. The ratio r of field strengths E' and E" from the desired and undesired stations at a point d' miles from the desired station and d" miles from the undesired station is then:

$$r = \frac{g'd''}{d'g''} \tag{4}$$

where g' and g" correspond to the radio gain g for the desired and undesired stations at the point in question.

In plotting our curves all the points in space were found for a given separation where the value of r was 8, 4, 2 or 1, corresponding to protection ratios of 18, 12, 6 and 0 db. Computations were made only for grazing angles up to 10°, extrapolating the vertical radiation pattern for the ASR-1 antenna between -4° and -10°. The + or the - sign in eq. (2) was used to compute g' and g" according to whether we wanted

a ratio of desired station minimum to undesired station maximum field strength, or desired maximum to undesired minimum field strength. These two categories describe the boundaries of the shaded areas in Figs. 1, 4, 7 and 10.

In computing the reflection coefficient $|R'|$ for 2900 Mc, a ground conductivity of 10^{-13} emu and a dielectric constant of 15 esu were assumed.

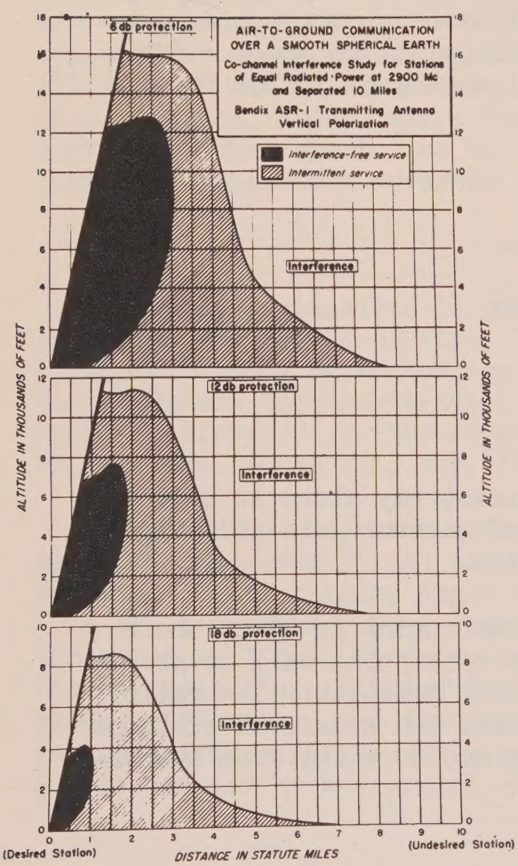

Fig. 1

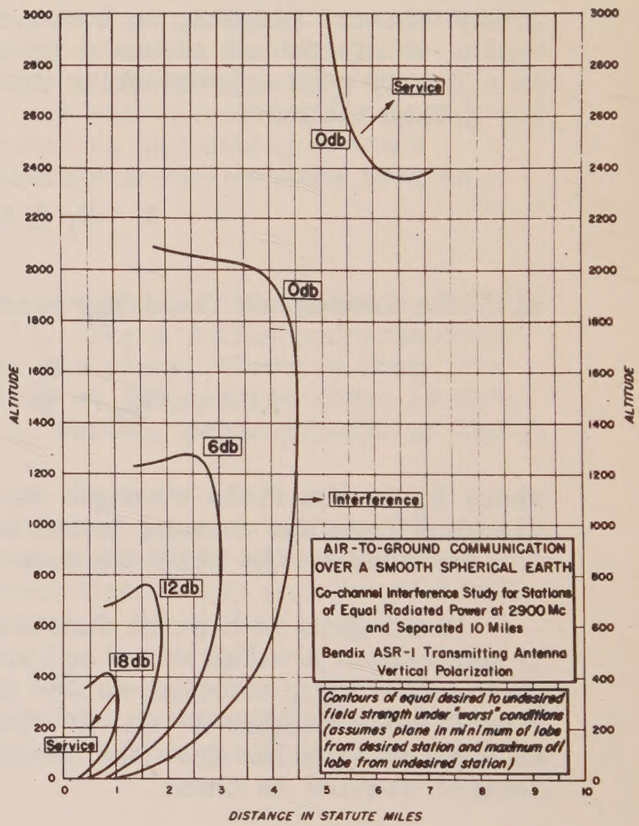

Fig. 2

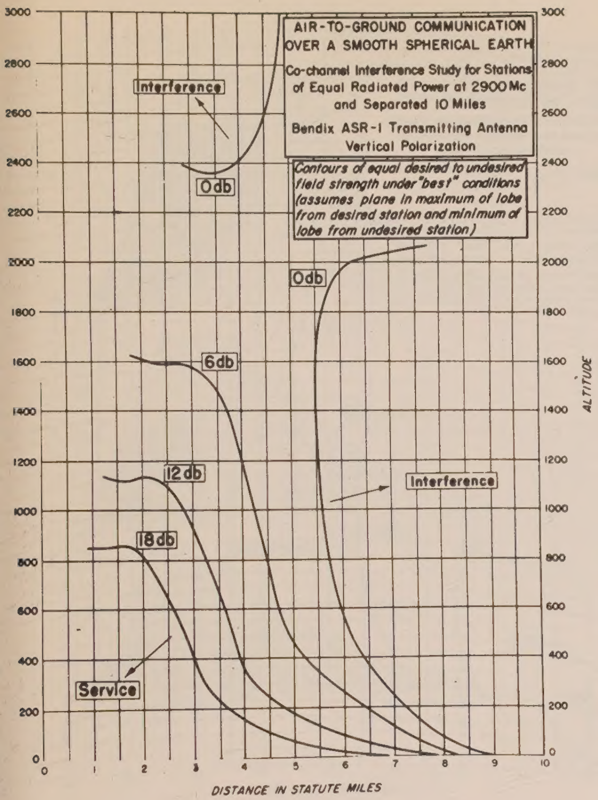

Fig. 3

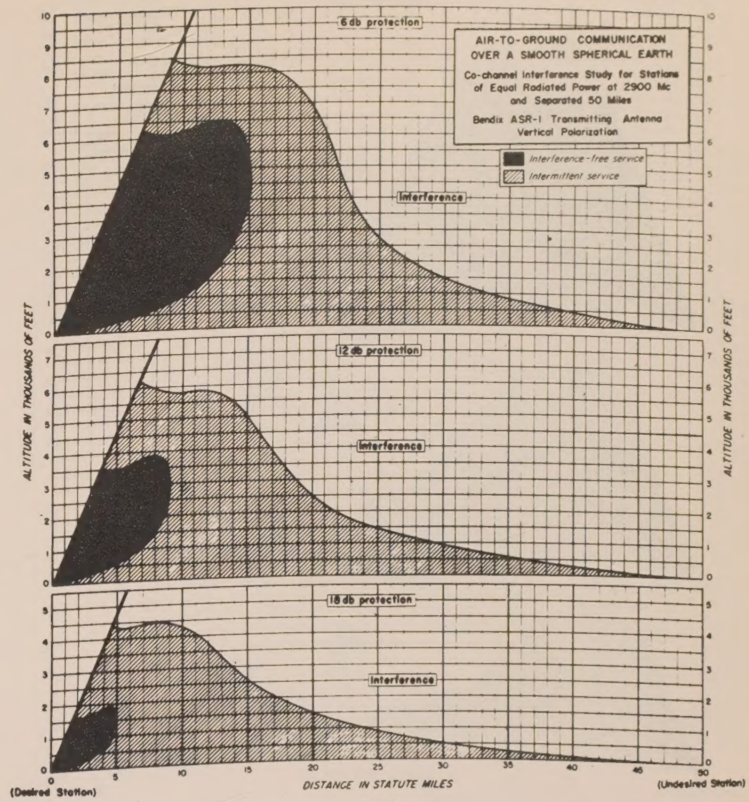

Fig. 4

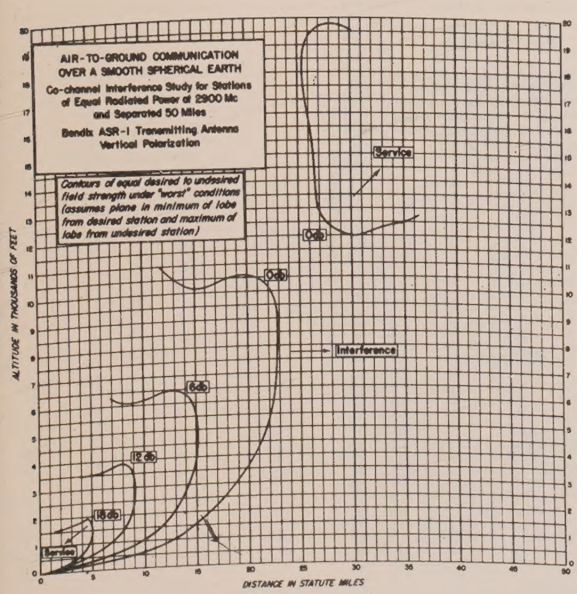

Fig. 5

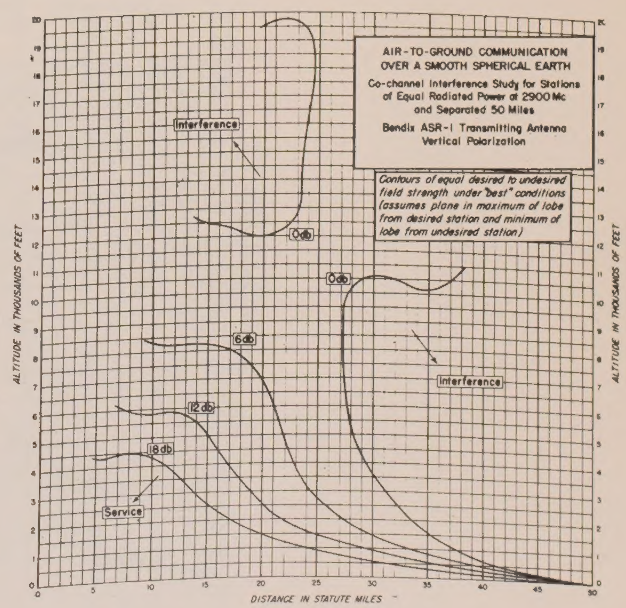

Fig. 6

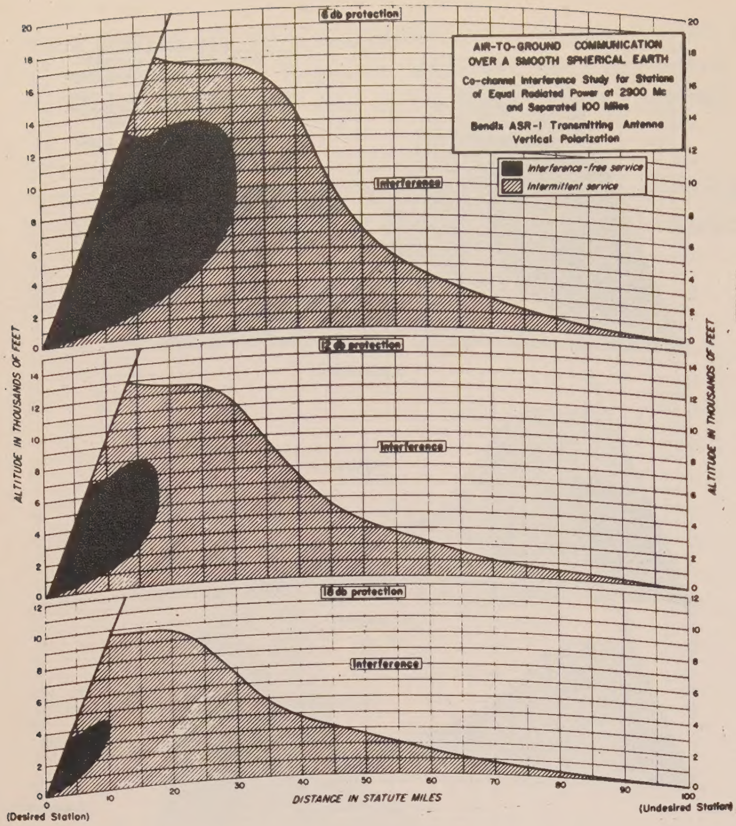

Fig. 7

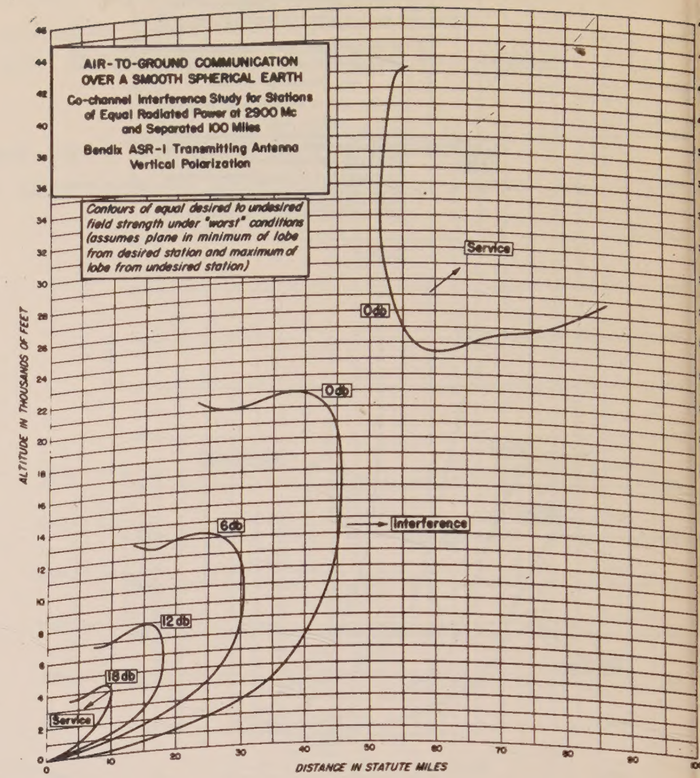

Fig. 8

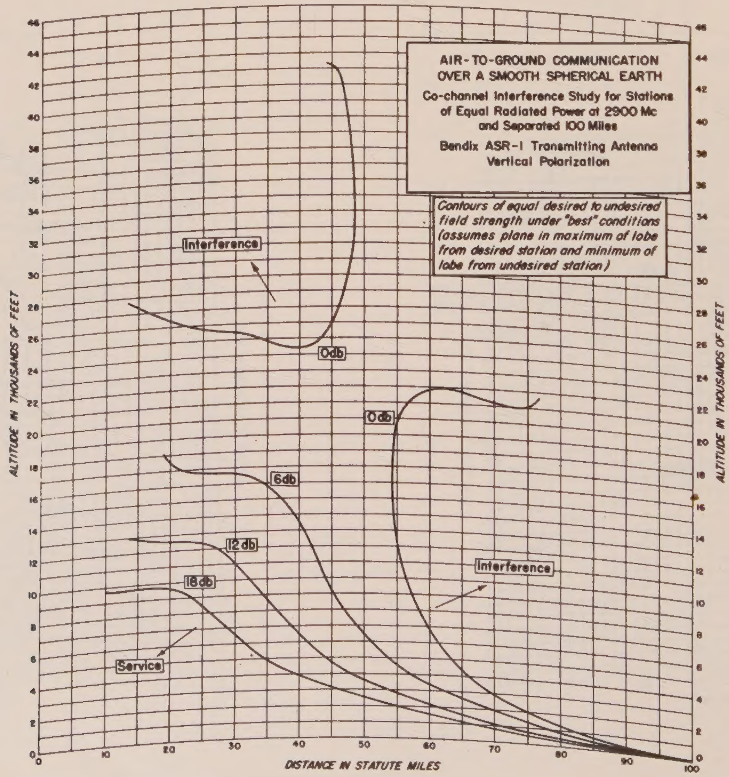

Fig. 9

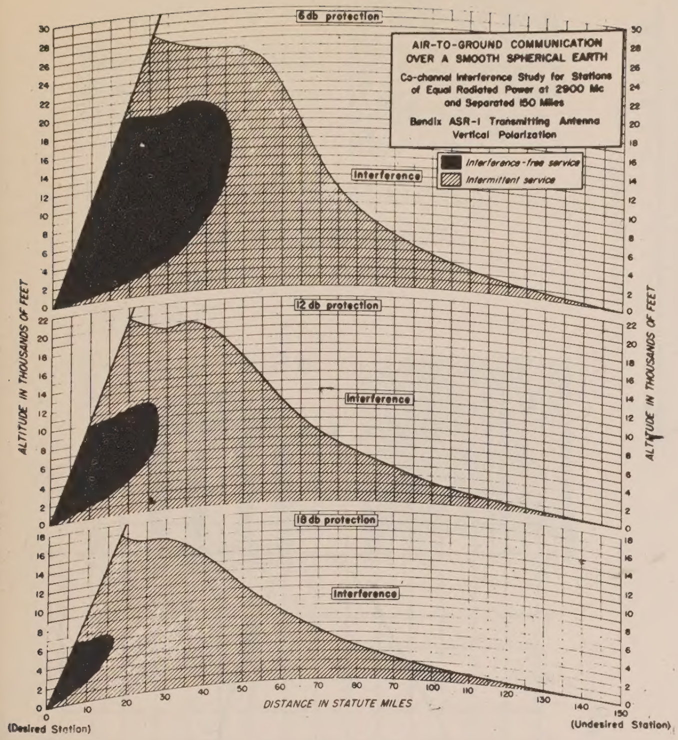

Fig. 10

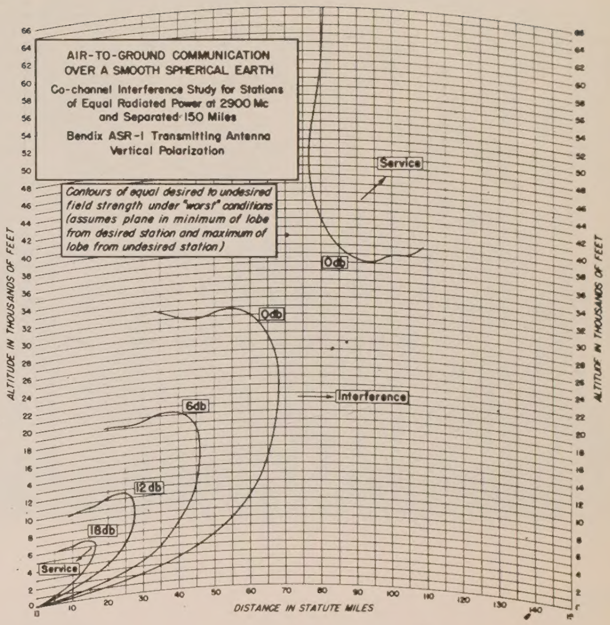

Fig. 11

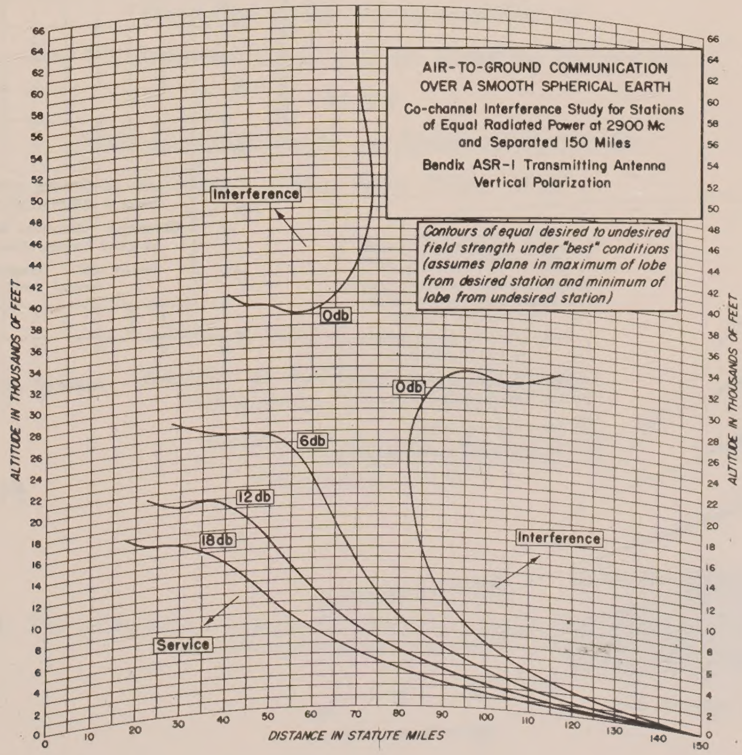

Fig. 12

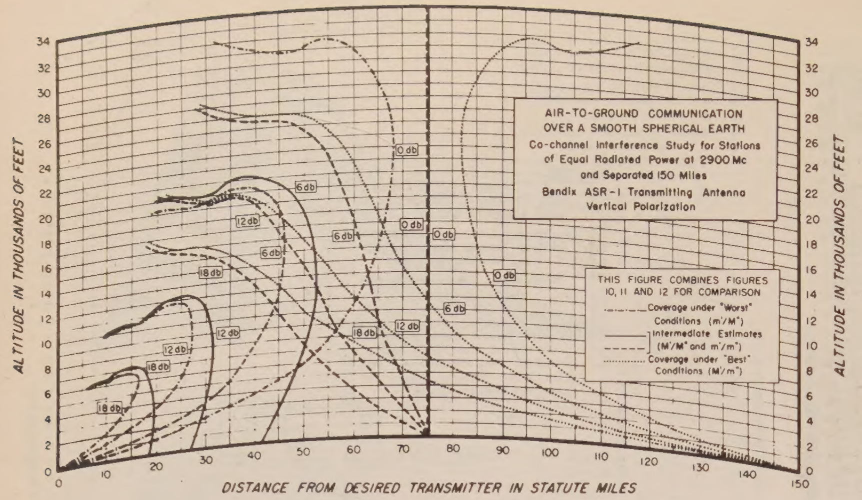

Fig. 13

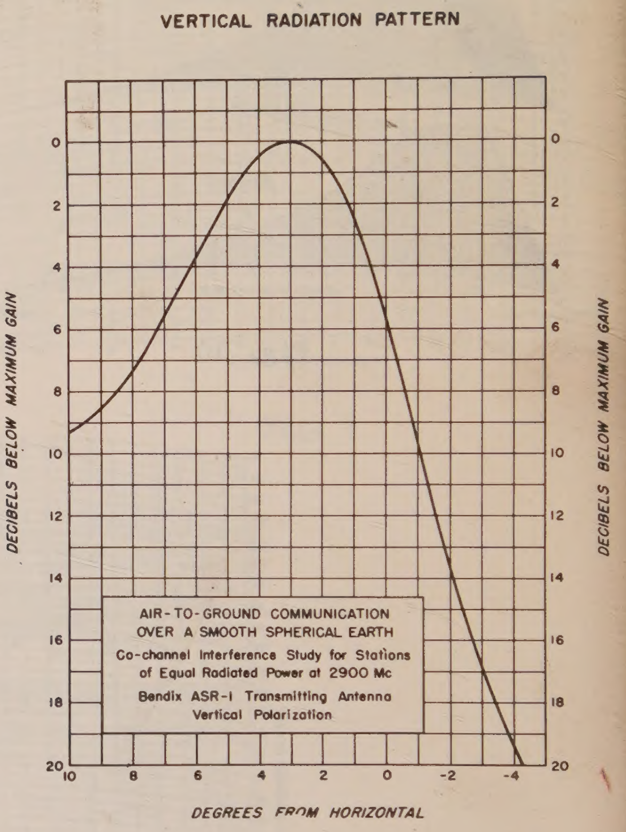

Fig. 14

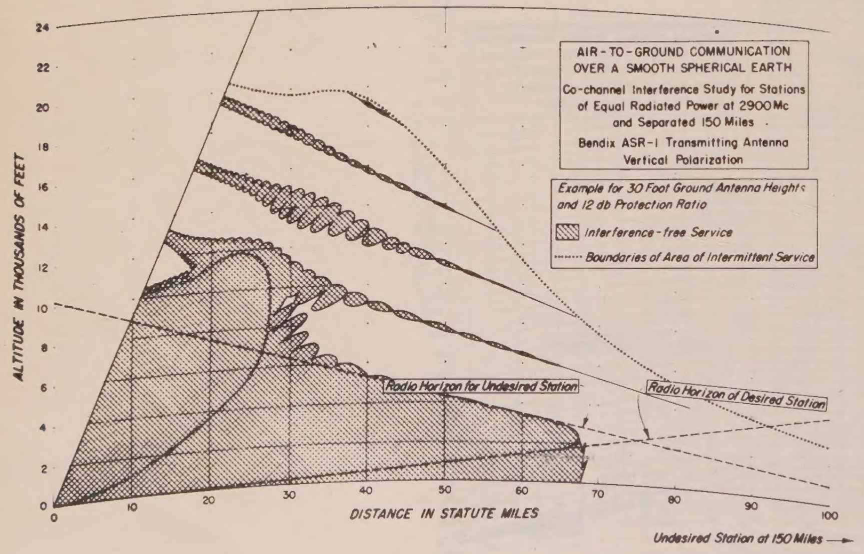

Fig. 15